Remotely Sensed Tropical Cyclone Structure/Intensity Changes

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LONG-TERM GOALS

Accurately map the three dimensional structure and intensity changes of tropical cyclones via satellite remote sensing data for both real-time analyses and as input to numerical weather prediction models.

OBJECTIVES

Develop techniques to analyze the three-dimensional (3-D) structure of tropical cyclones (TCs) in all-weather conditions. Enable the analyst to determine whether a tropical system has changed intensity via the organization of relevant cloud/rain bands and the formation of an eyewall or eye. Derive a methodology that will work well at night when Infrared (IR) data is typically poor and inadequate.

APPROACH

Passive microwave satellite data will be used to mitigate the current limitations of visible and infrared (vis/IR) data used to monitor tropical cyclone (TC) structure and intensity. 85 GHz digital data from the Special Sensor Microwave/Imager (SSM/I) channel is able to penetrate most non-raining clouds and the spatial resolution (12x15-km) can effectively map most rainbands and eyewall features. The ability to see through non-raining upper-level clouds represents a large advantage over vis/IR images and reveals otherwise unknown storm structural information. The ability to view TC internal 2-D structure around the clock is vital in knowing whether a system is intensifying, decaying, or remaining steady state and helps the analyst understand internal storm dynamics.

A database consisting of > 5,500 specially processed SSM/I images containing TCs has been created. Storms covering the entire intensity spectrum are included using historical SSM/I data archives and the data set is now updated in near real-time using links to the NRL TC web page (Hawkins, et. al, 2001). Time series studies are now possible since the analyst can view the required storm features and organization without the restrictions of upper-level cirrus clouds that frequently accompany a TC's intense convection, otherwise known as the central dense overcast (CDO).

The Advanced Microwave Sounding Unit (AMSU) is a passive microwave sounder that has two functions that assist in TC monitoring; 1) mapping the upper-level warm core temperature anomaly via vertical temperature profiles, and 2) using the 89 GHz channel to assist in determining eye size for the intensity estimation algorithm. Tropical cyclones are a heat engine and create an anomalous pool of

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14. ABSTRACT
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15. SUBJECT TERMS

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warm air above them that is directly related to their intensity. Therefore, if we can derive a method to map the warm core with satellite sounders, the community has an independent method to estimate TC intensities worldwide.

WORK COMPLETED

SSM/I passive microwave digital imagery from over 5,500 tropical cyclone overflights has been processed at NRL-MRY. The data processing techniques utilize specific image enhancement methods (Poe, 1990) to produce high quality outputs. The 85 GHz images and rainrate products are analyzed by both human analysts and provided as input to an automated computer vision technique. The computer vision method has been applied to over 1,500 TC samples meeting strict criteria and is now gearing up to incorporate near real-time data for additional tests.

AMSU passive microwave sounding data from the NOAA-15/16/17 polar orbiters have been processed for the past 30 months over TCs in both the Atlantic and Pacific basins. Significant effort has been focused on the Atlantic basin due to the availability of high quality aircraft reconnaissance validation measurements. Near real-time processing is now online and providing the research team with invaluable insight on how to mitigate intensity outliers and extend it to the western Pacific for eventual use at the Joint Typhoon Warning Center (JTWC).

TECHNICAL RESULTS

NRL is breaking new ground in mining the wealth of TC information available in passive microwave imagery. The ability to use the 85 GHz imagery to see through non-raining clouds and remove the inherent limitations with vis/IR imagery has enabled researchers to better understand the time evolution of TC development and decay. Direct comparisons with coincident vis/IR data have proven time and again that passive microwave data can assist in nowcasting both the position (relocations of 60-120 miles have occurred based on this data set) and intensity.

Passive microwave data is especially relevant at night when the analyst only has 4-5 km IR data to view; cold cloud tops may be unrepresentative of the low-level circulation center (LLCC). Shear conditions remove many of the cold clouds, but low-level clouds associated with exposed LLCC are very hard to see in IR data (Simpson, 2002). The CDO and shear conditions come at critical times in a storm's timeline and need to be mapped in real-time for warnings and for model bogus initialization to be accurate and effective. Examples are readily available on the NRL tropical cyclone web page: http://www.nrlmry.navy.mil/tc-bin/tc_home

Additional products using higher resolution Tropical Rainfall Mapping Mission (TRMM) Microwave Imager (TMI) have proven very useful. 37 GHz imagery penetrates further into the TC than 85 GHz and effectively gets below the scattering due to ice crystals aloft. Lee, et al., 2002 illustrate how the 37 GHz imagery and derived products can enhance storm features difficult to see or interpret in either 85 GHz data as well as vis/IR data sets. Both the 85 GHz and 37 GHz data can be used to map eyewalls before they typically are revealed in vis/IR imagery. Eyewall monitoring is a key factor in determining whether a storm's intensity should be upgraded or downgraded.

Internal eyewall cycles have been recently shown to occur much more frequently than previously realized due to inadequate sampling using vis/IR data. Figure 1 illustrates three (3) versions on concentric eyewalls mapped from SSM/I 85 GHz imagery. A systematic review of passive microwave data during 1997-2001 reveals that concentric eyewalls are highly correlated with storms reaching maximum sustained winds of 120 kts or higher. Approximately two-thirds (66%) of Atlantic basin storms and over three-quarters (75%) of western Pacific typhoons reaching best track intensities of 120 kts or more exhibited concentric eyewalls. This correlation is important for: a) interpreting passive microwave imagery, b) understanding TC short-term intensity trends, and c) understanding inner-core storm dynamics associated with eyewall evolution. Passive microwave data from SSM/I, TMI and AMSU were used to create the database.

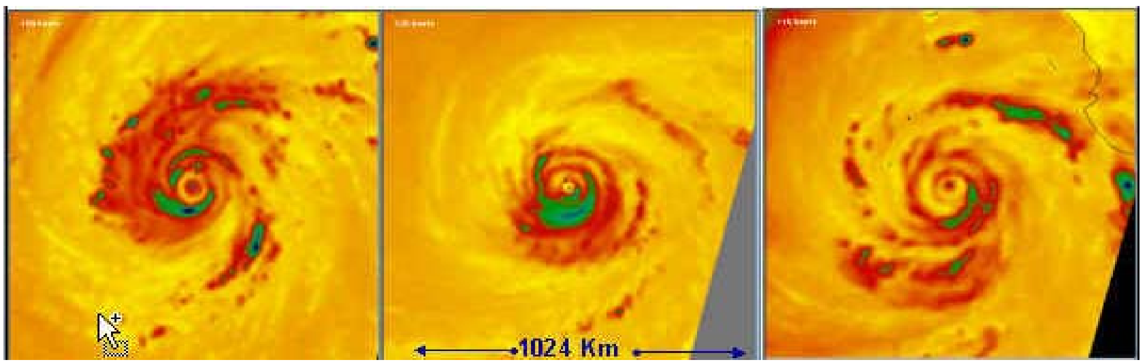

Figure 1. Three examples of double or concentric eyewalls occurring within different tropical cyclones using 85 GHz SSM/I brightness temperatures (Tb) images over a 1024x1024 km box. Typhoon Faxai (2001), Hurricane Guillermo (1997) and Hurricane Juliette (2001) all exhibit distinct double eyewall configurations (in some cases suggesting triple eyewalls) while encompassing various storm sizes and rainbands. Lower Tbs in blue and green are directly related to intense scattering due to frozen hydrometeors associated with very active convection.

The computer vision technique to recognize TC intensity from passive microwave imagery has been transitioned to 6.4. A database with ~ 1,500 specially processed SSM/I TC overflights has enabled the algorithm to achieve an RMS accuracy near 15-17 kts when compared to independent best-track storm maximum sustained wind speeds (Bankert and Tag, 2002). The specific focus is now on adding new methods to screen intensity overestimates for weak storms that exhibit very cold Tb near the storm center, but do not have a well-developed circulation.

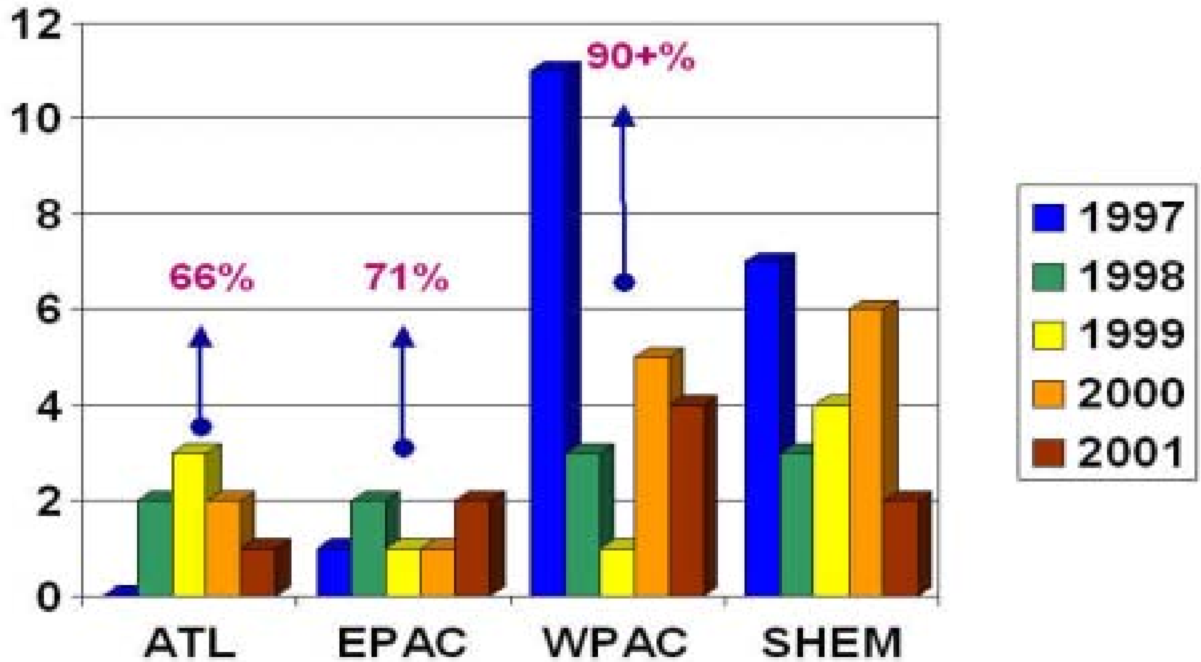

Figure 2: Number of tropical cyclones reaching a maximum sustained wind speed equal or greater than 120 kts for the Atlantic, Eastern Pacific, Western Pacific and southern hemisphere. The study time frame covers the years 1997-2001. Over 66% (two thirds) of all storms reaching 120 kts developed concentric eyewalls in the Atlantic and eastern Pacific, while the western Pacific statistics reveal 90%. 1997 was unusual due to 11 Super Typhoons during a very active and strong west Pacific season.

The AMSU TC intensity method using a warm core temperature anomaly module has proven very successful. Tests in the Atlantic revealed that accuracies similar to Dvorak errors (~ 12 mb) were achieved when compared to aircraft minimum sea level pressures. The main emphasis this year has been to incorporate an additional AMSU temperature channel. TC warm core anomaly vertical structures are not identical, thus multiple channels sensing different altitudes can check for anomalies not at standard reference levels (Brueske, et. a., 2002). Additional work incorporating the radius of maximum winds from all other sources has also shown to add skill to the AMSU intensity nowcast.

IMPACT/APPLICATIONS

The passive microwave demonstrations have had a profound impact on both our understanding of near real-time TC structure, intensity and evolution along with associated positive inputs to model and storm theoretical studies. Remote sensing estimates of independently derived TC intensities will significantly assist JTWC due to their lack of in situ or recon data.

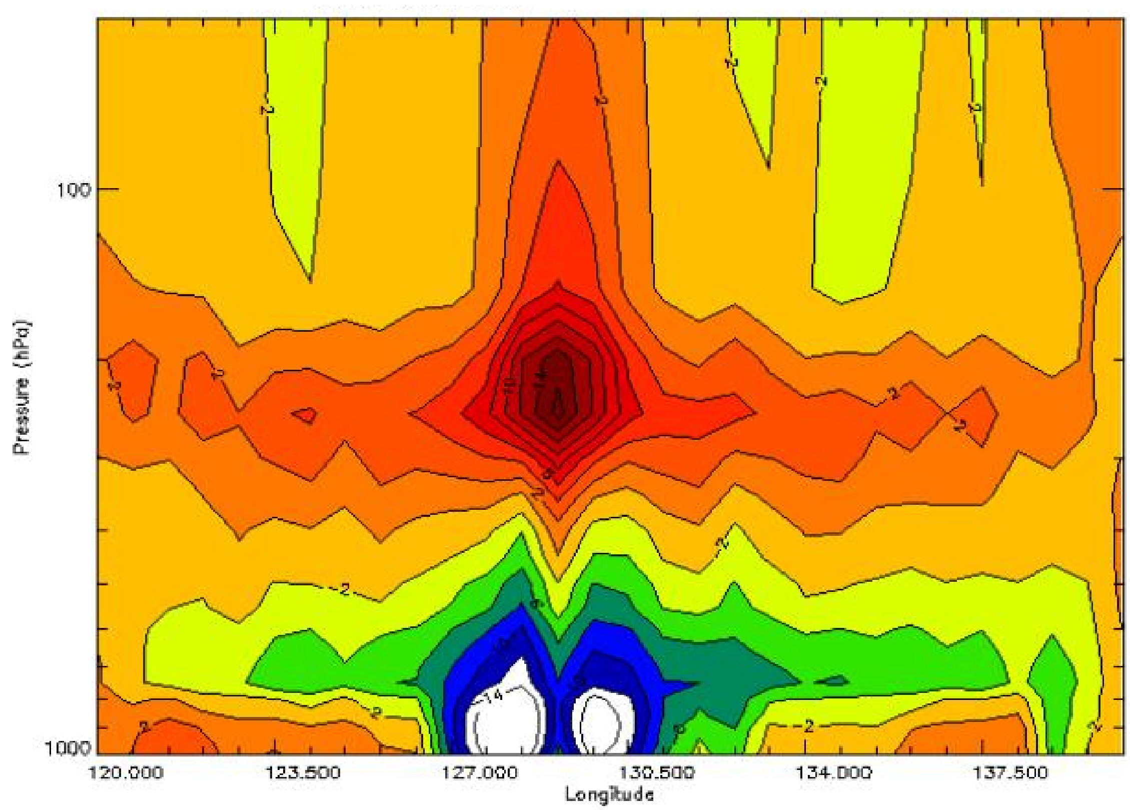

Figure 3. AMSU derived upper-level warm core temperature anomaly for Super Typhoon Mitag on March 5, 2001 at 1017Z. Maximum warming is centered near 200-250 mb with values exceeding 16 degrees C. Cold values at low levels outside the eye are anomalies caused by intense rain scattering. Contour intervals are every 2K.

TRANSITIONS

The capability to view and utilize passive microwave for TC structural mapping has been transitioned to 6.4 and more recently to operations at FNMOC. FNMOC now creates and maintains a slightly modified TC web page 24/7! The AMSU warm core temperature anomaly effort has moved a portion of it's effort to 6.4 and near real-time testing is underway with JTWC and NHC. The SSM/I intensity estimate module will be transitioned to 6.4 in FY-03.

RELATED PROJECTS

This project is closely related to 6.4 efforts sponsored by the Space and Naval Warfare Systems Command (SPAWAR PMW-155, Capt. Robert Clark, Program Manager), funded under PE 0603207N.

SUMMARY

The use of passive microwave data for TC monitoring has blossomed as a result of this research and corresponding 6.4 efforts. The NRL TC web page has gained worldwide acceptance and is routinely used operationally by all World Meteorological Organization (WMO) TC warning centers. The automated intensity algorithms using computer vision and AMSU data aloft are gaining acceptance within the research community and are beginning to do the same within the operational centers. The vertical integration of the ONR 6.2 effort with the SPAWAR 6.4 work unit has enabled rapid progress and transition of these remote sensing TC monitoring tools.

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